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REPORT ON

ELECTROLYSIS

BY

WINFIELD S. WILLIAMS

CHIEF ENGINEER BUREAU OF INSPECTION

TO THE

COMMITTEE ON SUPERVISION

OF PUBLIC IMPROVEMENTS AND EXPENDITURES

CIVIC LEAGUE OF SAN FRANCISCO

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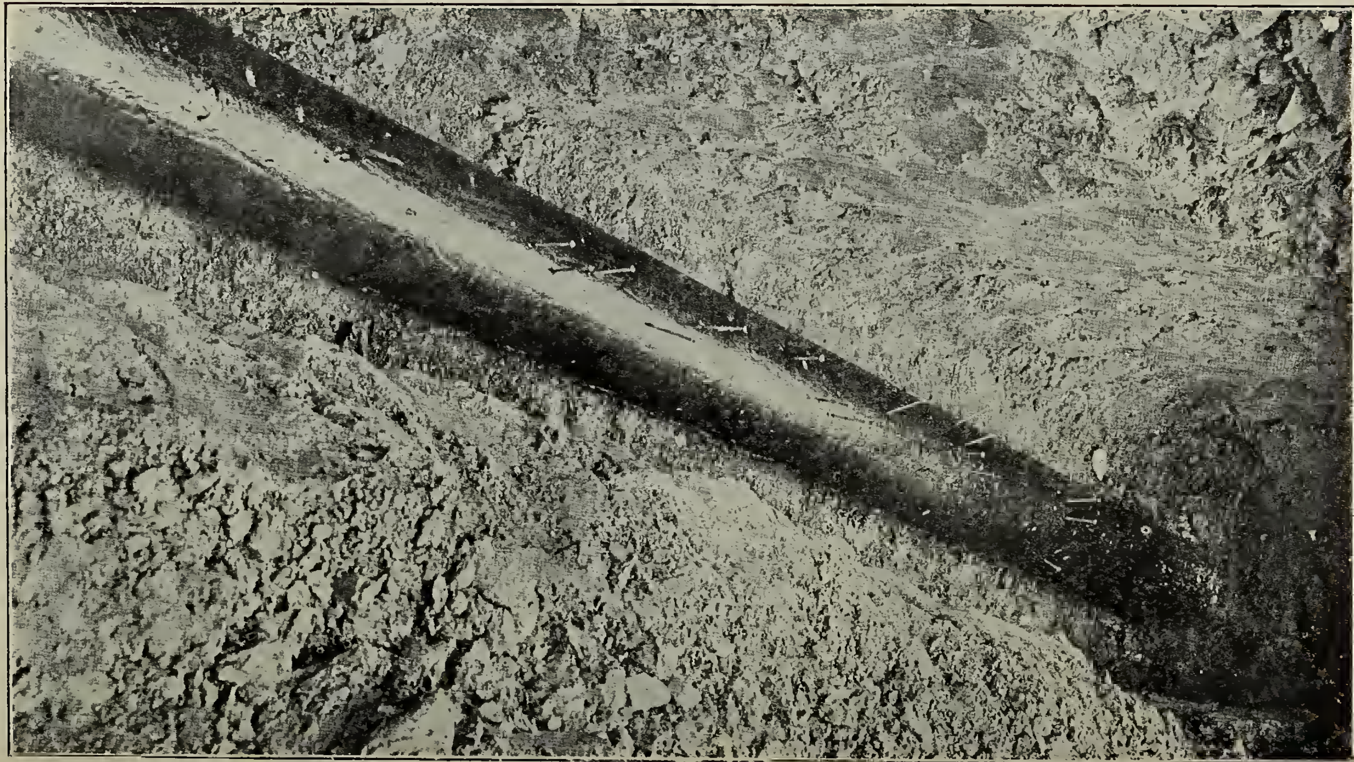
OCTOBER 1909

OFFICE OF

THE BUREAU OF INSPECTION

921-923 MONADNOCK BUILDING

PHONE KEARNY 3306



St. Louis, Mo.—Gas main laid two years ago in sandy clay soil; pipe so soft it could be cut by a knife. Tar coating entirely destroyed. Nails showing above have been driven entirely through pipe in some instances. Had this pipe been carrying water under 300 pounds pressure it would have burst several years ago.

Brownell

September 24th, 1909.

D. A. HAGENS,

Secretary Committee on Supervision of Public Improvements and Expenditures,

Civic League of San Francisco.

Dear Sir:—I transmit herewith Mr. Bergen's report on high pressure fire protection systems in operation in various parts of the country, together with my own report on the subject of Electrolysis and its destructive effects upon buried metallic structures. This latter I have attempted to prepare from a layman's standpoint, so that every taxpayer in San Francisco, whether technically trained or not, may be enabled to understand the subject and to realize the grave effects it will have on our system about to be installed.

Indeed, the two subjects that stand out most prominently in Mr. Bergen's investigations are the effect on insurance rates caused by the installation of a high pressure system for fire protection and the danger to pipes of such systems to serious and rapid deterioration, due to electrolysis. Every city visited has had trouble. In several of them, through systematic study and thorough investigation, the evil effects have been reduced to the minimum. But in many instances, such investigations have only been made after the pipes were practically ruined, necessitating the replacing of the same at great expense, together with the increased fire hazard, due to the absence of protection while the work of reconstruction was under way.

Very truly yours,

WINFIELD S. WILLIAMS.

September 1st, 1909.

WINFIELD S. WILLIAMS,

Chief Engineer, Bureau of Inspection,

Civic League of San Francisco.

Sir:—I have the honor to submit herewith a report covering my investigations of high pressure fire protection systems in service and about to be installed in various cities of the United States. Special attention is directed to the fact that wherever such systems have been installed, it has been followed by an immediate reduction in insurance, or contemplated raises in rates have been prevented.

The system designed for San Francisco will cover a greater area than that of any other city in the world, and will protect the holdings of a greater number of property holders than elsewhere. In order to be effective it must be kept in the highest state of efficiency at all times. Electrolytic deterioration of water pipes has caused the most serious trouble wherever the study of its prevention has been neglected. The problem of its prevention in connection with the proposed system should be taken care of at once, in view of the heavy pressure to which the pipes will be submitted.

Very respectfully,

FRANCIS P. BERGEN,

Assistant Engineer.

REPORT OF FRANCIS P. BERGEN

Assistant to the Chief Engineer, Bureau of Inspection, Civic League of San Francisco

(Mr. Bergen has recently returned from a tour of inspection of all the larger eastern cities, investigating their high pressure fire protection systems.)

The object of this report is to place before you in as concise a manner as possible the present status of the development of high pressure fire protection systems in this country, with information regarding the various systems that are now in use, together with data regarding contemplated systems. In every large city, it will be found that certain peculiarities such as topography, climatic conditions, density of population, abnormally high buildings, etc., are present, which necessitate the construction of a high pressure fire protection system along certain lines, but which would be entirely unfit for other localities. Some details, such as nature of material to be used, methods of construction to secure permanency of water supply at all times, in case of breakage of pipes, etc., most approved designs of valves, hydrants and hose, as well as other data of a like nature, can be used in all systems.

The question of the deterioration of the material of piping system, due to escaping electric currents, is to be considered, I understand, in detail in another report. What has been done in the eastern cities that have been visited regarding this matter, will, however, be briefly considered here.

Due principally to insufficient cross section of the metallic path for return electric currents as it leaves the cars, too large a percentage seeks other paths, such as the earth, water pipes, gas pipes and other conducting material. In so doing, due to the presence of certain salts in solution in the damp earth, electrolytic action takes place. If the iron water pipe be at a higher electric pressure, other things being equal, than the car rail, and is placed in such earth as noted above, the iron of the water pipe will be withdrawn, and will be deposited upon the rail, or upon any other structure that is at a lower potential than itself, or will be diffused in the earth. As a consequence, the thickness of the water pipe will be decreased, and a time will arrive when it will not withstand the pressure of the water inside, thereby causing a rupture. In treating of electrolytic action, there are many other phenomena to be considered, but the above will give an idea of what electrolysis is, so that the reference to it in what follows may be understood.

Chicago, Ill.—In Chicago, it was ascertained that the City Engineer has been gathering data both from existing and proposed high pressure systems, but neither plans nor specifications have as yet been made. An expenditure of $3,200,000.00 is contemplated. The capacity of the pumping station will be 30,000 gallons per minute against a pressure of 300 pounds per square inch. Triplex pumps, driven by means of gas engines, will probably be used. The distributing system of cast iron pipe will be about 50 miles long, to which will be connected about 850 hydrants, and will protect an area of 1,280 acres. Regarding the question of electrolytic action on the water pipes of Chicago, I may say that the Board of Supervising Engineers of the Union Traction Company, in the rehabilitation of the street railway system, have paid particular attention both to the installation of an efficient return circuit and to the proper bonding of the rails of the electric railway system, both of which will tend to reduce this action to a minimum. From the Commonwealth-Edison Company the method used in lessening this trouble on its extensive high tension electric cable system was ascertained. Due to the continuity of the sheathing on the cable, a very good electrical conductor is formed. Bonding by means of copper wire to the rails of the street railway system is made at specified distances. The result of the above work on the part of the Commonwealth-Edison Company, the proper bonding of rails and the installation of an efficient return circuit by the railway company, is that no destructive action from electrolysis is noticed on its cable system.

There is an agreement in force between the various electric railway companies and the Peoples Gas & Coke Company, by which the railway companies have agreed to reimburse the gas company for any and all damage that the stray currents may cause to the gas pipes.

A reduction of the insurance rates of 25 per cent. is assured when the high pressure fire protection system shall have been installed.

Cleveland, Ohio.—The high pressure fire protection system consists of two fire boats. On each boat are triplex pumps capable of delivering 5,000 gallons of water per minute against a pressure of 300 pounds per square inch. At important points of the city, land connections are placed, which enable the boats to pump water into a disconnected distributing system of cast iron pipe, six miles in extent, to which are connected hydrants of Matthews' patent. An area of 338 acres is protected. The City Engineer stated that as good results have been obtained from the use of the single groove cast iron pipe as with the double groove under high pressure. The mode of calking the pipes would necessarily make a difference, although calking in one operation with lead was used in experiments. The City of Cleveland has had much trouble from electrolytic action on its pipes. A few years ago a length of cast iron pipe of about 20 inches in diameter, installed in the neighborhood of the electric railway station, burst on account of being affected by stray railway currents. After being relaid, the railway company bonded the pipe with heavy copper cable and connected it with the negative bus bar. Electrolytic surveys are occasionally made; the maximum positive voltage to earth so far was fourteen volts. The affected area is closely watched in order that further destruction may not take place. The railway company is asked from time to time to improve its return circuit and to rebond its rails. Farther than this no other action has been taken.

A pumping station is proposed, together with an extension of the distributing system. On account of the inability of Cleveland to raise sufficient funds, it is not probable that the above mentioned station will be constructed in the near future. Connections are not at present made to either stand pipes on buildings or to sprinkler systems; it is problematical if they ever will be. A reduction of eighty cents per $1,000 on insurance premiums is proposed as soon as the pumping station shall have been constructed and the additional distributing system installed. The domestic supply is also used for fire fighting purposes.

Buffalo, N. Y.—This system consists of three fire boats, capable of pumping about 15,000 gallons of water against a pressure of 300 pounds per square inch. The above mentioned boats and a distribution system, consisting of 2½ miles of single groove bell-and-spigot cast iron pipe, to which are attached Matthew hydrants, with four hose connections, was begun in 1897. Trouble has been experienced in leakage from joints which are made in the ordinary way with lead. The lead of the joints is reinforced with a steel band for the purpose of keeping it in place. Electrolytic surveys are made occasionally, but no marked deterioration of the water pipes has been noticed. The electric railway systems of Buffalo pay particular attention to both the installation of an efficient return circuit and to the bonding of the rails with the result that Buffalo is very free from trouble to its water system caused by stray electric currents. A reduction of thirty cents per $1,000 on insurance premiums took place when the system was installed.

Worcester, Mass.—Worcester has installed a gravity system enabling a maximum pressure of 165 pounds per square inch to become available. About 20 miles of bell-and-spigot cast iron pipe protecting an area of 1,380 acres is in operation, in which the above pressure is continuously kept. The domestic water supply is also available for fire fighting purposes. The high pressure system is not as yet interconnected, but additions are now contemplated which will combine them. Connections are made to stand pipes on buildings and to sprinkler systems that are sufficiently strong to withstand the working pressure. No trouble has manifested itself as yet from electrolysis, neither has any systematic investigations been made to see just how serious, if any, the action is. This system was installed some years ago, and its pressure has prevented an increase in insurance rates.

Boston, Mass.—At the present time Boston has two fire boats capable of delivering 6,000 gallons of water against a maximum pressure of 200 pounds per square inch, protecting an area of 65 acres with a distribution system of 4,700 feet of bell-and-spigot single groove cast iron pipe. An extension of the distributing system, with a pumping station, involving an expenditure of $1,000,000 is contemplated. Water under pressure of about 35 pounds per square inch is kept in the pipes, but it raised to a pressure of 200 pounds per square inch during a fire. The trouble from leakage is nil and the deterioration from electrolytic action is very small. The electric railway's system of bonding, as well as the presence of efficient return circuits are such that the action on the water pipes is very small. Electrolytic surveys are made at stated periods. The City Engineer of Boston considers bonding of the pipes to the rails of the street railway system as a makeshift, and if said action does appear, localize it and get rid of it at the effected spots. In this way it will not manifest itself at other parts of the system. The hydrants are enclosed in a reinforced concrete enclosure. This method lessens the cost of repairs to hydrants.

Providence, R. I.—3,500 gallons of water per minute under a pressure of 114 pounds per square inch derived by means of gravity with a distributing system of 5.57 miles of bell-and-spigot cast iron pipe to which are attached 124 hydrants affords protection to 358 acres of territory. The leakage of the system in the year 1900 was 2487 gallons per day. Water is furnished to automatic sprinkler systems. Electrolytic action manifested itself in 1897. The city has made many examinations since they and from them it has been able to convince the street railway company that it is largely responsible for the damage caused by stray electric currents. Marked improvements have been made in the construction of its system with the result that the damage to the water pipes has been decreased from year to year. Continued vigilance is however deemed necessary.

Hartford, Conn.—A system consisting of gas engines driving triplex pumps capable of pumping 10,000 gallons of water per minute against a maximum pressure of 300 pounds per square inch with 13 miles of cast iron pipe, to which are connected 198 hydrants, protecting an area of 731 acres and costing $796,277 is proposed. If separate hydrants are to be installed on the high pressure piping system for street flushing purposes, they will be constructed so as to close when the pressure becomes equal to 50 pounds per square inch. Permanent connections to stand pipes and automatic sprinkler systems will not be allowed. It is advised, however, that stand pipes of sufficient thickness to carry water under a pressure of 300 pounds per square inch be installed so that connections can be made to the hydrants if it is later deemed necessary. A telephone system to be maintained and controlled exclusively by the city for its high pressure service forms part of the system. In 1893 a preliminary report was submitted to the Board of Water Commissioners regarding the electrolytic corrosion of the water pipes and their serious condition was at once manifested. Detailed examinations have been made since then. The co-operation of the street railway company was secured with the result that there has been a steady improvement in the electrolytic corrosion of the pipes.

Manhattan—On account of the very efficient electric system in Manhattan and the possibility of being supplied from many sources of power, electric motors driving centrifugal pumps are installed. The system consists of two stations, in each of which are five motors aggregating 4,000 horse power, attached to centrifugal pumps rated to pump 15,000 gallons of water under a maximum pressure of 300 pounds per square inch, but capable of pumping 20,000 gallons. The distributing system consists of 63 miles of bell-and-spigot cast iron pipe, to which are attached 1,300 hydrants arranged for the attachment of four lines of hose, one 4½ inches in diameter and the other 3 inches, and protecting an area of 1,454 acres, about one-tenth the area of Manhattan, and so situated that there is a hydrant within 400 feet of any building and in sufficient number to enable 30,000 gallons of water to bear on any single block without employing hose of greater length than 400 to 500 feet. Special connections such as tees, elbows, etc., are made of cast steel. the leakage in the Manhattan system with Croton water therein under a pressure of 35 pounds per square inch is 300 gallons per minute, principally at hydrant connections. An efficient telephone plant is installed and forms a part of the system. The majority of the portable fire engines have been removed to the outlying portions of the city and hose wagons have been substituted. A support is provided for the hose under high pressure; towers supported on hose wagons are also used.

When the high pressure fire protection system was first placed in operation there was great difficulty in obtaining firemen that were willing to handle the hose. It was not long before the prejudice against it was abandoned, and at present firemen would rather be connected with a fire house which operates on the high pressure system than with one containing a portable engine. The system was first placed in operation in July, 1908 and since then it has been called upon to fight many fires. Its success has been so great that city officials declare it has already paid for itself. The problem of fire protection was more expensive per acre and more complicated than in any other city in the country, as here is a region of congested risks, for their extent and character probably unequaled elsewhere in the world. So successful has this system been that if any additional proof of the effectiveness of it were needed, it is supplied by the fact that recently there has been appropriated $1,800,000 for its extension to a district where the density of population and the character of the buildings would make serious fire a grave catastrophe. There has been only one break in Manhattan's piping system and that was caused by the negligence of a contractor in failing to properly support the pipe under which he was working. Trouble from electrolysis has not manifested itself of recent years. The railway system of Manhattan is thoroughly bonded, besides having a very efficient copper return. No trouble from this source is contemplated. The method of operation is a follows: In front of the telephone operator is a large panel on which is placed the numbers of the telephone stations and their locations. Those governing hydrants supplied with water from one pumping station are printed in black; those governing hydrants supplied with water from the other station are printed in red. The system of signalling used between the telephone operator and the switchboard operator is of a marine form. The operation is as follows: A signal comes to the telephone operator from a station, the hydrants of which are supplied from the pumping station at which he is located. A signal from the telephone operator to the switchboard operator may signify to start one unit and pump against a pressure of say 100 pounds per square inch. The switchboard operator starts the motor from the board and operates the valves so that water under the above pressure will be forced from the pump. The pressure can be increased by intervals up to 300 pounds, if necessary. Further signalling will place the entire equipment of the stations in operation. Auxiliary pumps, valves, etc., are likewise operated from the switchboard. The various pumping units are so arranged that a defect in its operation or the breakage of its piping, etc., will in no way affect the operation of the others. Vacuum pumps are installed in each station on the suction side of the pumps to be used in case it be desired to pump salt water. A valve is installed on each pump which allows it to bypass any surplus water directly into the suction side of the pumps, thereby saving the pumping of an equal amount of water through the distance of the full suction head. The other station can be operated in the same manner or both pumping stations can be operated in parallel, forcing water into a common piping system. Valves and special connections are so placed that no part of it will be without water due to a breakage in said system. There is no change in insurance rates.

Brooklyn, N. Y.—The system consists of two stations, in one of which are five motors aggregating 4,000 horse power, and in the other, three motors totaling 2,400 horse power, all of which are connected to centrifugal pumps rated to pump 24,000 gallons of water under a maximum pressure of 300 pounds per square inch, but capable of pumping 32,000 gallons. The distributing system consists of 22 miles of bell-and-spigot cast iron pipe, protecting a territory of 1,360 acres. This system was placed in operation in October, 1908; its operation is similar to that of Manhattan. Electrolytic action is being taken care of in a systematic manner.

Philadelphia, Pa.—On account of the very efficient gas system in Philadelphia, nine gas engines are connected to triplex pumps capable of pumping 10,000 gallons of water against a maximum pressure of 300 pounds per square inch, through a distributing system of seven miles of flange cast iron pipe, to which are attached 166 hydrants, protecting an area of 512 acres. Much trouble has been experienced from pipes breaking at the flanges caused by an unequal settling of the ground. The packing between flanges is made of ten ounce canvas, impregnated with coal tar. The flanges are joined by means of steel bolts. This form of joint has been the cause of much electrolytic trouble due principally to it being of a low electrical conductivity. There has been no case of a single failure in the plant since it was started in 1903. During the first year of operation the larger pumping units ran 337 hours and the smaller unit 198 hours with a total pumpage of 27,000,000 gallons. The average cost per thousand gallons pumped, including all the experimental runs, which were by far the major portion of the service, was 12½ cents, but for a large fire of five or six hours duration, the cost of pumping is barely over five cents per thousand gallons. The total cost of repairs for pumping plant up to December, 1905 was $3.05. The entire station can be placed in service in less than seven minutes. The mode of operation is very similar to that of the Manhattan system, save that the operation is not as centralized as in the latter place. The first important consequence when the Philadelphia plant was started was a reduction in insurance rates of twenty-five cents per $100 insured within the protected area. An appropriation of $500,000 has been made for an extension of the system, consisting of a gas engine station similar to that already installed and capable of pumping 12,350 gallons of water per minute against a maximum pressure of 300 pounds per square inch and the installation of 25 miles of universal joint cast iron pipe.

Baltimore, Md.—A steam pumping plant capable of forcing 10,000 gallons of water against a pressure of 300 pounds per square inch through a distributing system of open-hearth welded steel 15 miles in length and protecting an area of 360 acres is contemplated. A coating impervious to the elements, salts of the earth, etc., is to be used both on the outside and on the inside of the pipe. A compression joint made out of the same material as the pipe is to be used. From the standpoint of electrolysis, this form of joint is such that the electrical conductivity per unit of length will be very nearly equal throughout the entire length of pipe. The lesser weight of steel per unit of length for the same working pressure as compared with cast iron will allow greater lengths of steel pipe to be handled thereby decreasing the number of joints in a given length of pipe line which will be an advantage. It is also the iutention to lay the pipe at a greater depth in the ground than is ordinarily done, so as to avoid any changes in direction due to obstructions such as gas and water pipes, sewers aud conduits. The greater depth that it is to be laid in the earth will increase the distance it is from the street railway tracks, thereby increasing the electrical resistance to the flow of the escaping electric current from the track to the pipe. The coating of pipe will also increase electrical resistance between the rails and the pipe. Hydrants and valves are to be placed in special reinforced enclosures, thereby enabling repairs and inspection to be easily and cheaply made. Stand pipes on buildings of correct construction and streugth will be allowed to connect with the high pressure system. A telephone system is contemplated in connection with the installation.

Lynn, Mass.—At the works of the General Electric Company, Lynn, Mass., the steam turbines are being manufactured. Four Curtis horizontal steam turbines operating with steam at 150 pounds pressure per square iuch and of a horse power of 600 each, have been forwarded by the above mentioned company. These turbines are direct connected to the centrifugal pumps manufactured by the Byron-Jackson Company, of this city, and at present on the fire boats. In addition, the above named company is at present manufacturing eight horizontal Curtis steam turbines each of a capacity of 750 horse power. They are to be placed in the salt water pumping stations and are to be direct connected to Byron-Jackson centrifugal pumps now in the process of manufacture by that company. The city of San Francisco is well represented at the General Electric Company's works in the person of Mr. Davol, with the result that San Francisco will possess unusually high grade and efficient steam turbines as prime movers for the pumps in the high pressure pumping stations as well as on the boats.

Detroit, Mich.—It may be noted that for some time the city of Detroit has been collecting data relative to the installation of an independent high pressure fire protectiou system, and, as soon as completed, preliminary estimates will be made and appropriations asked for its installatiou. Regarding the destructive action of the stray electric currents from the railway system, investigations have shown that there is considerable destructive actiou, but the total amount is not known. No steps have been taken by the street railway company to counteract such conditions.

Foundries—The foundries of the United States Cast Iron Pipe Foundry Company at Bessemer, Alabama; Anniston, Alabama and Chattanooga, Tennessee, were visited and a thorough inspection of the manufacture of cast iron pipe, as well as the method of testing, dipping, etc., was made. The pipe will be delivered from the three places mentioned above much faster than the city will be able to place it in the ground. The rigid inspection of the pipe by a sufficiently large corps of experieuced inspectors of Robert W. Hunt & Company, together with the desire of the manufacturer to strictly follow the specifications, assures an exceptionally high grade of pipe for San Francisco.

Very respectfully submitted,

FRANCIS P. BERGEN.

ELECTROLYSIS

Its causes and effects and methods of prevention.

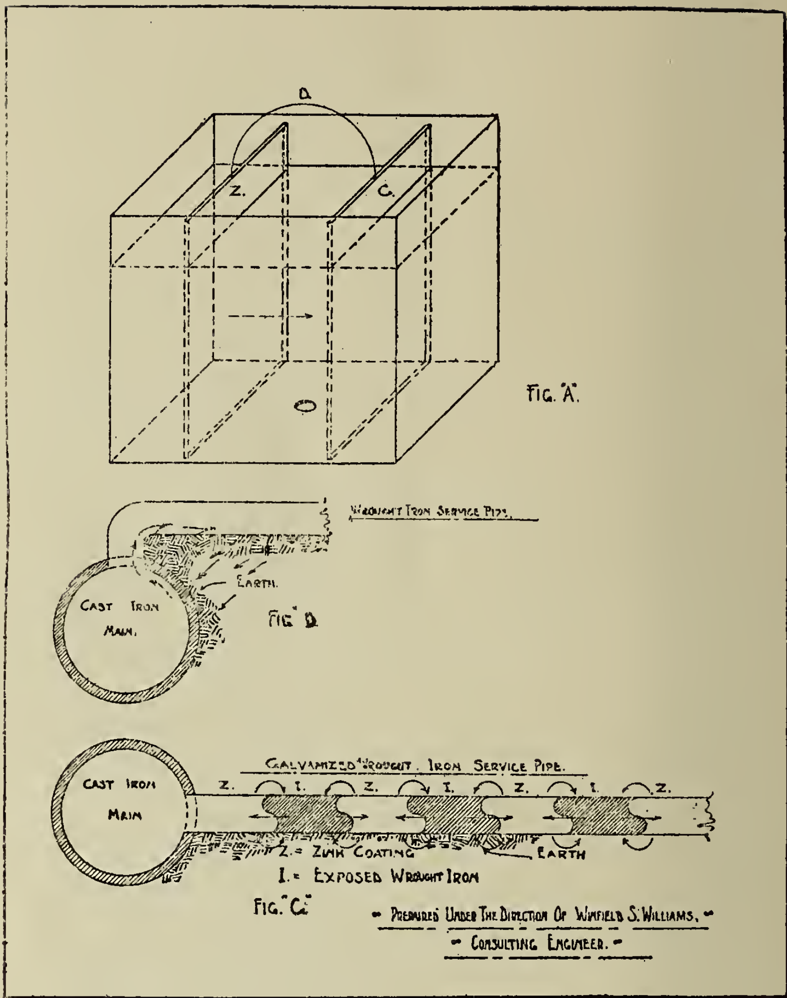
(WRITTEN FROM A NON-TECHNICAL STAND-POINT)

The subject of "Electrolysis," so vital to public welfare, as applied to electrolytic deterioration of underground metallic structures, due to the diversion of a portion of the return current from the single wire electric railway system, is at present causing and in the past has caused more diversity of opinion, both among experts and the public, than any other electrical problem. The great confusion of evidence created mainly by contradictory reports, is due to a lack of sufficiently sound theoretical and practical knowledge upon the subject. Many conclusions are unwarrantedly arrived at without a proper and full consideration of the phenomena involved. The theorist has no practical knowledge along the lines which he is supposed to advise, and he whose knowledge is based upon experience alone is ofttimes led to make unsound statements which are not consistent with well known laws of electricity and electro-chemistry. This confusion only tends to broaden the already unpleasant relations which, as a rule, exist between the owners of single wire street railway systems and the owners of underground metallic structures.

For a proper understanding of the action of stray electric currents on metallic masses buried in the earth, it has been thought well to give a brief and non-technical description of the influences at work.

For some time it has been known that if two dissimilar metals be immersed in a slightly acidulated solution, and metallically connected, a current of electricity will flow from one metal through the solution to the other, completing the circuit via the connection between the second and the first metals. The effect of this is to cause that metal, from which it flows into the solution, to dissolve and lose weight. For example: In Figure A, let Z and C represent respectively zinc and copper plates, both of which are immersed in an acidulated solution O, Z and C being connected by a conductor of electricity D. The flow of current will be indicated by the arrows, and the zinc plate will be gradually consumed in the solution. If the copper plate C be replaced by an iron plate, the direction of flow of current will be as noted above, and the zinc plate Z will as before be consumed, while if the zinc plate Z be replaced by an iron plate, the current will flow from the iron plate through the solution to the copper plate and will lose weight. The above illustrates the actions of a galvanic couple in which an electric current is generated at the expense of one of two dissimilar metals immersed in a solution. The direction of the flow of current will depend both on the metals immersed and to a lesser extent on the solution in which they are placed. Experiments show that if a plate of wrought iron be connected to one of cast iron and placed in a solution of soil taken from a street excavation moistened with water, the direction of current would be from the wrought iron plate through the solution to tbe cast iron plate.

In our water systems placed underground, we usually use wrought iron pipe coated with zinc for supply service connections and cast iron pipes for supply mains. If the soil be moist, a local current of electricity will be generated, and will flow from the service pipe through the earth toward the


a
Z.
C.
FIG. "A".
WROUGHT IRON SERVICE PIPE.
EARTH.
CAST IRON MAIN.
FIG. "B"
GALVANIZED WROUGHT IRON SERVICE PIPE.
Z. I. Z. I. Z. I. Z. I. Z.
CAST IRON MAIN
Z. = ZINC COATING
EARTH
I. = EXPOSED WROUGHT IRON
FIG. "C"
PREPARED UNDER THE DIRECTION OF WINFIELD S. WILLIAMS,
CONSULTING ENGINEER.

cast iron main. The wrought iron service pipe will be gradually consumed, losing first its zinc coating and then its own structure. The zinc coating will protect the service pipe as long as it remains intact, for in a zinc-iron couple the direction of flow of the current is from the zinc to the iron. This action is illustrated in Figure B.

We may have a condition in which a service pipe (wrought iron), from which the zinc has in places been removed, connected to a cast iron main. This is illustrated in Figure C. In this case local currents will manifest themselves as indicated by the arrows. Closer circuits are formed from the zinc through the soil to the exposed wrought iron pipe and back through the material of the pipe to the zinc coating. As the current from the zinc to the wrought iron is of greater potential than from the wrought iron to the cast iron, and opposed, the current from the zinc to the wrought iron will prevent the current from leaving the wrought iron for the cast iron. In this way the wrought iron service pipe will be protected, even though the zinc does not form a complete coating. A remedy suggested for the prevention of the corrosion of wrought iron service pipes by local currents consists in attaching metallically to it at frequent intervals plates of zinc so located that they may be renewed when necessary. The above will tend to show how metallic structures other than water pipes may be destroyed by local electric currents. So far local action only has been considered.

If, however, two iron plates are immersed in an electrolytic solution and an electric current from some outside source be passed from one through the solution to the other, the plate from which the current leaves for the solution will be gradually consumed, but at a greatly increased rate over that in the instance of a true galvanic couple. This action is illustrated in Figure D, in which A and B are two plates immersed in a solution and connected to the terminals of a generator C. The current will flow as shown by the arrows, with the consequence that A will be gradually consumed while B may or may not be affected, depending on conditions. If the above plates designated as A and B be copper and the solution be copper sulphate, the metal removed from plate A will become copper sulphate and be dissolved in the solution, while at plate B sulphate of copper would be decomposed and give up metallic copper as a deposit on the plate.

Plate B, under such conditions, would increase in weight nearly in the same extent as plate A was consumed. In the above the plate from which the current appears to leave is called the positive plate, and that one to which it appears to flow is called the negative plate. The plate that is consumed is always the positive plate. In the earth various pipes or buried metallic structures may be considered as positive or negative plates, surrounded by an electrolyte composed of the various salts of the soil dissolved by the rain, or other impregnated earth. The current causing electrolytic action (local action being not considered) may be derived from the electric lighting or street railway systems.

With one exception, the several commercial utilizations of electricity as a medium of the transmission of power require a complete metallic circuit insulated from the earth. The exception is that of the grounded street railway with the single trolley. Leakage from power and lighting circuits may cause current to flow into the earth, but in elec-

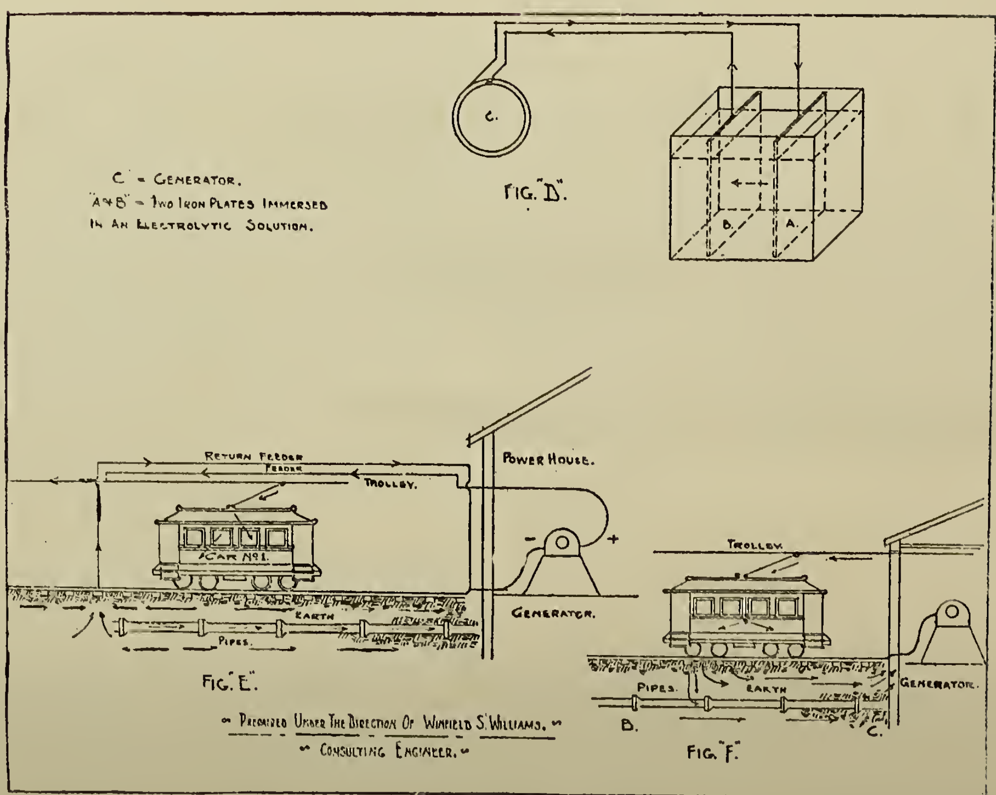


FIG. "D".

FIG. "E".

FIG. "F".

~ PREPARED UNDER THE DIRECTION OF WINFIELD S. WILLIAMS. ~
~ CONSULTING ENGINEER. ~

trolytic deterioration of underground metallic structures the grounded street railway only has to be seriously considered.

In the earlier days of street railway development, the electric system was operated with the negative side of generators connected to plates placed in the earth. It was soon found, however, that the current did not flow as freely through the earth as was expected. The next step was the use of the rails as a return path in connection with the earth. It soon became evident that the resistance of the rails as a return circuit could be decreased by the use of a mechanical bond placed between consecutive rails in addition to the connection made by fishplates. The next development was by the use of cast and welded joints. (It will not be the endeavor at this time to enter into the merits of the various forms of bonds.) The latest advancement is shown by the installation of heavy copper wires connected at intervals to the rails as return feeders. The above has been given for the purpose of showing the necessity of a return circuit of as low a resistance as possible and the means that have been used to accomplish this result. In addition to the rails, earth and return feeders, metallic structures placed in the earth will tend to act as a part of the return feeder system.

Thus we have: (1) The auxiliary copper return feeder circuit, usually placed on poles, but connected to the rails at certain points.

(2) The rails uninsulated from the earth.

(3) The earth, particularly that portion in the neighborhood of the rails.

(4) The buried metallic structures, such as water and gas pipes, placed in the earth. These are shown diagrammatically in Figure E.

Since the various parts of the return circuit as enumerated above are in parallel the laws governing the amount of electricity flowing in parallel circuits must hold, namely, the current flowing in any section of a parallel circuit varies inversely as its resistance. Regarding the proper size of the auxiliary copper return, it should be of such dimensions as will offer but little resistance to the flow of the return current and should be tapped onto the rails at well selected points. The size in any particular instance will depend on the number of cars in use, and hence on the amperage of the return current. The effectiveness of any certain form of rail considered as part of the return circuit will depend on the thoroughness in which the joints between adjacent rails are made. The joints should be well constructed both from a mechanical as well as from an electrical standpoint, and should be of such a nature that they will not deteriorate with age. It is not necessary to go into details regarding the forms of joints, save that they should comply with what has been said; the main thing being that they should be of a permanent nature and of low resistance. Regarding the earth as a path for the return current it may be said that its conductivity will depend on various conditions, such as moisture, character of soil, etc., all of which may tend to make its resistance to the flow of current greater or smaller.

From an electrolytic standpoint, we know that where a current of electricity leaves the rails of the single wire railway system and passes into the earth, the electrolytes that lay adjacent to the rails and pipes split up electro-chemically into non-corrosive elements and acid-forming radicals. The corrosive radicals appear upon the surface of the rails and the non-corrosive elements appear upon the surface of the pipes. If, however, the pipes be electrically positive to the rails the current will pass from them into the earth and liberate the acid-forming radicals upon the surface of the pipe. Hence, if at any point the rails be electrically positive, they will be deteriorated, and if, on the other hand, the pipes be electrically positive, they in turn will be seriously corroded by robbing them of metal which will recombine in the various compounds of iron salts.

The acid-forming radicals consist chiefly of nascent oxygen and chlorine, which are very active in producing corrosion. Since the electrodes in the case under consideration are of iron, the counter electromotive force of electrical polarization is eliminated, there being no difference of electrical potential of counter electromotive force to contend with, making the situation from an electro-chemical situation far more simple than when dissimilar metals are involved. The rate of electrolytic deterioration of any piping system depends upon one general law, namely, the rate of deterioration is directly proportional to the product of the current in amperes and the time or duration of the current flow. The theoretical amount of iron passing from the surface of a buried underground structure in one year by a current of one ampere flowing from its surface is about twenty (20) pounds. With lead, for instance, the deterioration is three and one-half times as large. Consider Figure F. It is seen that the current will pass from the generator to the trolley wire, through the motor to the rails. Through the rails, earth and pipes it flows back to the power house. There are two paths open for it, one consists of the rails and the other a combination of the earth and the buried pipes. As has been noted, the current flowing through these two paths in parallel is inversely proportional to the resistance of these two paths. Therefore, in a general way, a considerable portion of the current will leave the rails at A, flowing into the water pipe at B, and will again leave the water pipe at C and enter the rails. Here, then, is an electric current flowing between metallic structures that may be called electrodes at places in the return path from the motor to the power house. All that remains, then, to promote electrolytic action is the presence of some solution which will act as an electrolyte. This is found in the earth. Referring to the diagram it can be seen that if there exists in the ground sufficient moisture and some metallic salt, electrolytic action will take place between the electrodes A and B and between the electrode C and the rails. The metals of this electrolyte will be deposited at B and on the rails, while the active part of the electrolyte will be found at A and C. Consequently, corrosion of the metallic structure may be expected at A and C and at all points where current is found leaving the metallic structure. At A the flow of current is such that there will be a loss of metal of the rails and at C there will be a loss of metal of the pipes. In either case the loss of metal will cause the resistance of the return circuit to be increased. The withdrawal of metal from the rails is not of such importance as that from the gas and water pipes, since they are under pressure. As the thickness of the metal of the pipe decreases, a time will come when they can not any longer withstand the pressure from within and bursting will result. In the case of cast iron we find that on account of the presence of graphite

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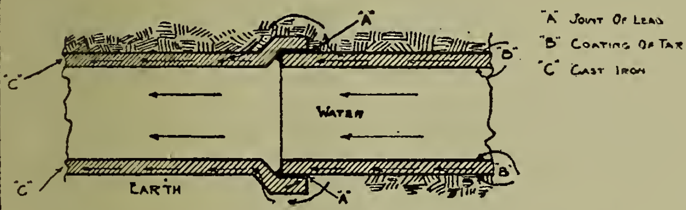

Fig. "G". Section Of Bell And Spigot Cast Iron Pipe.

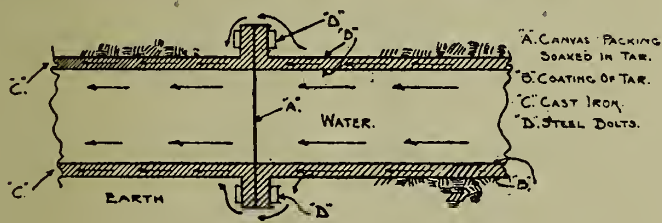

Fig. "H". Section Of Flange Cast Iron Pipe.

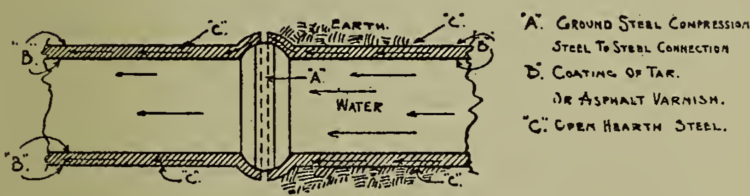

Fig. I. Section Of Open Hearth Steel Pipe With Steel Compression Joint carbon, which is not acted upon by nascent oxygen and nascent chlorine, the deterioration is not so rapid as is the case of wrought iron. When tar coated cast iron pipes are electrolytically affected, a tubercular formation is formed, resulting in pitting of the pipe. The depressions are the result of greater current density at the places in question, caused by the adjacent soil coming into closer contact with the surface of the pipe. An untarred cast iron pipe suffers more uniform deterioration than does a tarred cast iron pipe. If the pits be arranged longitudinally a sudden rupture is liable to occur, but if they are not arranged in any particular way a clean eaten hole is formed upon rupture. It has been found that ordinarily calked cast iron pipe rarely ever carries more than a very small portion of the total current leakage from the track of a single trolley system. The earth usually shunts from 10 to 40 per cent. of the return current, which, however, spreads out into vast dimensions, being governed by the resistance of the neighboring section of the earth. Throughout the area which this escaping earth current occupies it encounters numerous pipe lines. In the outlying or negative districts the current densities are light, but in those districts where the current returns to the rail the current densities increase, causing much deterioration of pipes in that section. We may have sections of a piping system affected by the currents passing from the earth to the rails in a vertical direction, but with no current flow along the length of the pipe. It is from current flowing as above defined rather than along the pipe lines that increases electrolytic deterioration and makes the subject confusing, and for this reason the installation of insulating joints is practically useless in preventing electrolytic corrosion upon pipe lines. As will be shown, the method of calking presents a joint of high resistance much greater per unity of length at the joint than in any other section of pipe lines.

Greater current than ordinary will flow through the pipes by the presence of one or more joints of high electrical resistance in the track. Hence, electrolytic action in any metallic structure which may occur in the earth path of the return current is almost directly proportional to the faultiness of the construction in the rail return. Regarding the electrolytic action that takes place in a section of pipe we may consider Figure G, which shows sections of two adjacent cast iron pipes, and Figure H, which shows sections of two adjacent cast iron flange pipes. A heavy coating of tar varnish, which is a non-conductor of electricity, is placed with a thickness of $\frac{1}{16}$ inch both on the inside and on the outside of the pipe. At A is shown a joint of lead, which as time goes on is chemically changed to an oxide of lead, which in turn is a non-conductor of electricity. We will assume that portion of the return electric current that traverses the pipe to flow from the right to the left, as shown by arrows. At the bell-and-spigot ends of two adjacent pipes it meets with a section of high resistance. A small amount of current will flow via the high resistance joint, but a larger amount will pass from one pipe to the other via the earth. As previously shown, the earth may be considered as an electrolyte and the current in passing from one pipe to the other via the earth will withdraw metal from one pipe in the direction of the other, as shown by the arrows, thereby weakening the pipe at this point.

Figure H shows the section of a flange cast iron pipe with steel bolts and tarred canvas packing. The steel bolts are affected by electrolysis much more than is cast iron, and consequently the steel bolts will break down faster than the adjacent cast iron of the pipe. This has been one cause of the somewhat rapid deterioration of the high pressure piping of the Philadelphia system. In contrast to the above is shown in Figure 1 a section of open hearth steel pipe with steel compression joint. At the joint no insulating paint is used, and as a steel to steel surface is present the resistance to the flow of electricity at the joint is the same or nearly the same as in other sections of the pipe line. Baltimore, Md., is installing this system of piping for its high pressure fire protection systems. The maximum length of heavy cast iron pipe that is considered economical to handle is twelve (12) feet, necessitating a joint of high resistance spaced throughout the pipe line at the above distance apart, whereas with steel pipe sections of thirty (30) feet or even larger can easily be handled. It will thus be seen that the number of joints is materially decreased, and as has been explained, their resistance is no greater per unit of length than that of any other section of the pipe line. The object of going into detail regarding the electrolytic action possible in a section of pipe is to obtain a clear idea of such actions, not however because it is general, for practice has shown that usually it is not. In the so-called "drainage" method of attacking the electrolytic corrosion problem where the pipes are made to carry current we may have such electrolytic deterioration at the joints, as has been noted above. The defects of the "drainage" method are considered later.

A complete investigation of the deteriorating effect of electrolysis necessitates a complete electrical survey of the piping system under every day operation of the street railway system. To do this it is not alone necessary that volt meter readings should be carefully taken, showing difference of electrical pressure between the pipes and the rails, but also resistance readings should be made, giving the resistance of the path of flow of the electricity in the piping system. From this data the value of the current in the piping system at various sections can be calculated. For the proper investigation a number of portable instruments, preferably of the Weston manufacture, should be used, and readings taken at least every 500 feet of the piping system. The data so obtained can be plotted and the two areas, positive and negative, can be easily ascertained. From the point of destruction of the piping system those sections which show where the iron is being removed from the pipes are of importance. It is absolutely useless to take only difference of pressure readings and likewise useless if but comparatively few readings are taken.

The best and safest plan to prevent the evils of electrolytic deterioration is to avoid the grounded circuit. This can be best done by the adoption of the double trolley wire. The cities that use this are Cincinnati, Ohio, and Washington, D. C. Nevertheless, there may even with this system be some leakage, but the electrolytic corrosion caused should be trivial. The greatest impediment in the installation of the double trolley is, of course, its cost. It appears that the single trolley has come to stay, and with it a certain state of electrical affairs naturally resulting from its use. Perfect immunity from electrolytic corrosion can not exist in cities where the grounded system is used. It is now agreed among railway engineers that the evils of electrolytic corrosion can be so reduced that the owner or owners of underground metallic structures will have little cause for complaint. The most **important thing to be done is to increase the return circuit to the highest available efficiency, making the electrical resistance so low by perfect bonding of rails and the installation of return feeders that little current can be diverted into the earth** and upon the various underground metallic structures. To do this requires skill and expense.

THE DRAINAGE METHOD

In some cities the underground metallic structures are connected, usually in the vicinity of the power house, to the rails or negative side of the generator. The amount of current that the pipes will carry after such connections are made will be greatly increased, the conditions depending upon the efficiency of the bonding. Its harmful effects also depend upon the nature of the material of the pipe and the efficiency from an electrical standpoint of the joints. The greatest danger of connecting the piping system to the rails is that it will establish positive areas in some other section with very serious results. Insulated pipe joints have been proposed to lessen and cure the evils of electrolytic corrosion, but it is nearly unanimously agreed that it is a makeshift. Of course, they prevent the flow of current along the pipe line, especially when newly installed, but they do not prevent the flow of current from passing around the joints through the earth; hence, we see electrolytic corrosion in systems where they are installed. It is the earth currents that pass to, over and from the surface of the pipe lines which bring destruction, regardless of the electrical resistance of the joints in a pipe line, whether purposely insulated or as in an ordinary lead calked joint. Tar coating and all ordinary forms of painting seem to succumb to the action of nascent chlorine, which is liberated by electro-chemical action.

CONCLUSIONS

From the above the following deductions may be drawn: Electrolytic destruction of pipes buried in the earth is due either to action of local galvanic currents or to the fact that a considerable proportion of the current used by single trolley street railroads to move their rolling stock returns from the car to the power house by way of the pipes. In the first instance the action is very slight, but in the latter case it often becomes an extremely serious matter. If the buried pipes in question were put together with joints of the same conductivity as the pipes themselves, and if the current could pass from the track to the pipes and from the pipes to the generator in the power house, over conductors of similar nature properly bonded, the mere fact that a current of electricity utilized them as a pathway would be of little moment. But where current flows through the earth and enters the pipes and at all places where it jumps around leaded or insulated joints and at points where the same leaves the pipes to flow to some other conductor, there is where trouble is sure to occur.

In San Francisco a high pressure fire protection system is about to be installed. Something over ninety-one miles of cast iron pipe, coated to a thickness of $\frac{1}{16}$ inch (inside and outside), will be laid, practically all of which is to be in territory affected by return currents from the street railway system. Leaded joints of high resistance, as compared to the iron of the pipes, are to be used throughout. The nature of the soil in the major portion of the territory is either sand or clay, carrying considerable water. In the lower section of the city, where made ground is encountered, will be found an abundance of salt water. Here there are found the elements which will hasten electrolytic deterioration, provided leakage current from the street railway be present. It is not to be presumed that the system in operation in San Francisco is any different in this respect that those operated in other cities. From the accompanying report will be noted the conditions that exist in other sections of the country. Also a glance at the frontispiece made from an actual photograph taken in St. Louis, Mo., will convince the most casual observer that where cast iron pipes become so soft on account of electrolytic deterioration as to admit of wire spikes being driven into them, the situation is grave indeed.

The high pressure fire protection system is being constructed at an expense of approximately $5,000,000.00. The pipes are to withstand the pressure of 300 pounds to the square inch. The protection of property from fire is at stake; therefore, steps should be taken at once to reduce electrolytic deterioration to the minimum.

Suggestions that will, if followed, produce the best results are:

(1) A complete survey to be made, consisting of volt meter readings, resistance of path of current in earth and current values in pipes, earth and rails; same to be made as soon as the system is installed, and at least once every year thereafter.

(2) A thorough examination of the bonding of the railway system and the installation of the necessary copper cables as ground returns, thereby shunting the current from the earth and underground structures.

(3) The non-installation of any connection between the rails and the pipes, as well as the non-installation of insulation joints in the piping system.

Respectfully submitted,

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